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This research deals with motor responses to common objects and with the cognitive representations of such responses. A "priming" paradigm was used to assess whether an advance signal about a relevant hand shape (the "prime") would facilitate judgments about the sensibility of actions performed with objects. Primes pertained to (a) the size of the functional hand shape and/or (b) whether the hand acted as a prehensile or nonprehensile instrument. Priming was found to be effective when both these features were specified and training on the prime signal required that the shape be explicitly enacted. Partial primes and training of verbal responses to the signal were ineffective. Examination of actual manual responses to objects indicates that interactions involving different hand shapes have a common timecourse during reaching and preshaping until relatively late, when the precision of the ultimate motor act differentiates among large and small, and prehensile versus nonprehensile, shapes.

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Summary

This research deals with motor responses to common objects and with the cognitive representations of such responses. A "priming" paradigm was used to assess whether an advance signal about a relevant hand shape (the "prime") would facilitate judgments about the sensibility of actions performed with objects. Primes pertained to two features of a hand shape: the size of the functional hand surface, and whether the hand acted as a prehensile or nonprehensile instrument. Priming was found to be effective when (a) both features of the shape were specified, and (b) training on the prime signal required that the shape be explicitly enacted. Partial primes, or those where training required only verbal responses, were ineffective. Examination of actual manual responses to objects indicates that interactions involving different hand shapes have a common timecourse during reaching and preshaping until relatively late, when the precision of the ultimate motor act differentiates among large and small, and prehensile versus nonprehensile, shapes.

I. Research Objectives & Summary of Progress

This project's primary objective is to investigate the cognitive representation of actions, particularly interactions of the hand with common objects. It is assumed that such representations mediate planning for actions, preparation, and possibly provide practice effects. Specific research foci are twofold: The first issue is whether there is an association between hand shapes and objects that is sufficient to enable cross-activation (priming) to occur. The second issue is how manipulatory intention -- specifically, the shape of the hand in ultimate contact of the object -- affects the nature of reaching and preshaping.

With respect to the first issue, we have successfully demonstrated priming between motoric representations of hand shapes, and representations of the meaning of interactions with objects. We have further shown that the basis for the observed priming effect is not entirely verbal/semantic in nature, but rather builds on specifically motoric representations. This work is reported in detail in the last section of this report.

With respect to the second issue, we have observed the course of reaching and preshaping of the hand for interactions with objects (e.g., picking up a glass). Although this work is in an early phase, it indicates a common element in early stages of reaching, with differentiation of the hand shapes later, according to the precision of the response required.

More specifically, subjects were videotaped as they reached for common objects so as to contact them functionally. Four ultimate modes of contact were distinguished: clench, pinch, palm, and poke. The first two are prehensile and the latter two nonprehensile; the first and third involve large hand surfaces and the others small. From the videotaped record, the onset times of several events were coded (relative to the time of object exposure): liftoff of the hand, first forward impulse of the arm, first finger movement, identifiable preshape, and contact with the object.

The four shapes differed in the time from object exposure to the first movement (hand liftoff), suggesting differences in the time to plan the response. However, they did not differ in the interval from first movement to full preshape, suggesting that a common program may underlie preshaping of diverse types. The preshapes differed again in the time from preshaping to contact. This period comprised approximately the last half of the entire interval and thus is likely to correspond to the deceleration phase in the arm movement, a phase that is known to be sensitive to the precision of the ultimate response. Consistent with this view, the large shapes were faster than the small over the interval from preshape to contact, and the nonprehensile shapes were faster than the prehensile. Greater precision is required for small shapes (contacting smaller surfaces) and prehensile responses, and this may underlie the slower final stages of the shaping activity.

II. Publications Planned and Forthcoming

1. In Press: Klatzky, R.L., Pellegrino, J.W., McCloskey, B. P., & Doherty, S. "Can you squeeze a tomato? The role of motor representations in semantic sensibility judgments." Journal of Memory and Language. -- This publication reports results of priming studies.

2. Planned: Pellegrino, J. W., Klatzky, R. L., McCloskey, B. P., & Doherty, S. "Effects of manipulatory intention on preshaping and reaching." -- This paper will report results of the reaching/preshaping study. Submission to Journal of Motor Behavior is likely.

III. Participating Personnel

1. Roberta L. Klatzky & James W. Pellegrino, co-PIs
2. Sally Doherty (6/87-4/88), Research Associate
3. Brian McCloskey, graduate Research Assistant
   Ph.D. expected 1/89
   "Motor Interference with Motoric/Semantic Priming"

IV. Professional Interactions

1. Presentation of priming work at poster session of the American Psychological Assn. Convention, Atlanta, Ga., August 1988. "Motor response categories and knowledge about objects." Authors: McCloskey, Klatzky, Pellegrino, & Doherty.

2. Participation by Klatzky in Review of Air Force Sponsored Basic Research on Attention and Perception, 15-16 September, 1988, U.S. Air Force Academy, Colorado Springs.

V. Detailed Report of Priming Studies

A detailed report of the research on motor/semantic priming follows.

Can You Squeeze a Tomato? The Role of Motor Representations in Semantic Sensibility Judgments

Roberta L. Klatzky James W. Pellegrino Brian P. McCloskey

Sally Doherty

University of California at Santa Barbara

Imagine yourself standing in the produce section of a supermarket, when someone asks you if the tomatoes are ripe. You may now imagine picking up a tomato and giving it a (gentle) squeeze. In many everday encounters with objects, we commonly invoke such actions of the hand, such as when opening a car door or dialing a telephone. In this paper, we explore the possibility that these motoric patterns become part of the representation of objects and can be used in evaluating potential interactions with them.

In previous research (Klatzky, McCloskey, Doherty, Pellegrino, & Smith, 1987), we provided evidence for robust associations between (a) knowledge about objects and their function, and (b) representations more directly related to the motor system. These latter representations were of the shape the hand takes in interaction with objects. This research supported the existence of general categories of hand shaping that could be related to many common objects and events. The hand-shape classes were defined by the crossing of two binary variables: (i) the size of the hand surface contacting an object (large -- involving multiple fingers and palm, vs. small -- involving one or two fingers, alone or with the thumb), and (ii) prehensility (whether the contacting fingers were flexed or extended). These variables defined four prototypical hand configurations, which can roughly be specified by the words poke (small size, nonprehensile), pinch (small, prehensile), palm (large, nonprehensile), and clench (large, prehensile).

In an initial experiment, subjects were asked to generate object names in response to verbal hand-shape cues (e.g., cued with "clench", they might generate "doorknob"). Conversely, they were also given the name of an object and asked to rate each hand shape for relevance to it, indicating what function the shape would serve. (For example, the clench shape would be used with a softball for the function of throwing.) There was substantial overlap among subjects as to the object names generated in response to a hand-shape cue. Well over half the generated objects were named by more than one subject, with up to half the subjects naming the same object. Ratings also showed agreement on object/hand-shape pairings. The four hand-shape categories were largely paired with different objects, although some objects could be used with different hand shapes, given different functional contexts (e.g., picking up a stapler with a clench or stapling with the palm).

A second experiment used unfamiliar forms (e.g., a styrofoam hemisphere) to determine the relationship between these hand-shape classes and two structural variables -- how far an object projected toward the viewer from its back surface, and the area of the projecting surface in the frontal plane. Subjects were asked to name the hand shape (of the four choices) that seemed most appropriate to each form. A highly regular response surface was derived, by plotting subject agreement against the two structural variables. This showed regions unique to each hand shape, within which forms generated high agreement and fast responses, with boundaries of ambiguity leading to slower responses. For example, forms with little depth and small surface area regularly elicited the "poke" response, but as depth increased, there was a transition to a "pinch" response. Despite these regularities, a model derived from the structural data to predict the hand-shape classes associated with common objects did not fare well. The nature of its specific failures pointed to the importance of an object's function, as well as its structure, in determining its hand-shaping associations. For example, a dime has the low depth and small area that elicits "poke" in the structural model, but is pinched in a functional context (picking up).

The results of the two studies supported the existence of reasonably discrete hand-shape prototypes that have strong associations to objects in functional contexts. These prototypes are cognitively accessible, insofar as subjects can make consistent judgments in the absence of an overt motor response.

The present research focused on the utility of these representations. We propose that when manual interactions with objects are represented cognitively, for example, when planning for an overt act or evaluating its possible consequences, then representations of the hand, like the prototypes that we have studied previously, become activated. Further, we suggest that these motorically based representations may play a functional role, by allowing for cognitive simulation. It is possible, then, that judgments about the feasibility and consequences of manual interaction with objects will be facilitated by advance activation of an appropriate representation of the hand.

The paradigm used to test the utility of motor representations in semantic judgments was a variant on the familiar priming task (Meyer & Schvaneveldt, 1976). We investigated whether priming of a hand-shape class could facilitate judgments as to whether or not an activity with an object was sensible. For example, squeezing a tomato is a functional activity associated with the clench shape, whereas squeezing a window is not sensible. On each trial, subjects made a sensible/not-sensible judgment about a phrase describing some activity with an object, such as "ring a doorbell." They were primed on some trials with a cue representing the hand-shape category most appropriate for performing that activity. The question of interest was whether the prime would facilitate the sensibility judgment.

One can conceive of two mechanisms for priming effects in the present task. One idea is based on the interpretation of semantic priming in terms of activation flow within a semantic network (Meyer & Schvaneveldt, 1976). This mechanism seems unlikely in the present ~~case~~, because prototypical hand shapes would be linked to many different objects and functions, severely diluting the potential for activation of any one target.

Another mechanism for prime-produced facilitation is suggested by the literature on the functions of imagery. (See Finke & Shepard, 1986, for a recent review.) In the case of visuospatial imagery, there is evidence that the activation of prototypic images facilitates, or even is necessary for, semantic judgments. Imagery appears to provide a medium for manipulating and interrogating spatial information. Images appear to allow us to infer spatial relations that were not encoded deliberately and to solve problems in which such relations are critical. For example, one may use an image to determine whether Seattle is North of Duluth, whether the letter B has an identical image when rotated 180 degrees in the picture plane and in depth, or when verifying some properties of objects such as whether pineapple leaves are spiny (Jolicoeur & Kosslyn, 1985). A reading/listening comparison has been used to support the idea that certain judgments, such as whether an orange is smaller than a grapefruit, require imagery in order to be verified (Eddy & Glass, 1981; Glass, Millen, Beck, & Eddy, 1985). The evidence for use of imagery is faster verification time when the judged sentences are heard than when they are read.

Motor imagery has also been the target of some investigations, although the extent to which it can be distinguished from visuospatial imagery is unclear. Perhaps the largest literature is that on mental practice of actions and its facilitation of subsequent performance. A recent review of this literature (Feltz & Landers, 1983) concludes that mental practice does have some effect, which appears to be more on cognitive preparation than on muscular actions per se. Goss, Hall, Buckholz and Fishburn (1986) found that individuals scoring high on a test of motor imagery showed faster acquisition of a complex shape-tracing movement; interestingly, these individuals were also high on visual imagery (and indeed, no one was found that was high on movement imagery and low on visual imagery). Visual imagery of actions as well as overt actions themselves have also been found to enhance retention of verbal materials (Saltz & Donnenwerth-Nolan, 1981; Backman, Nilsson, & Chalom, 1986). Distinct interference effects on visual imagery and overt action led Saltz and Donnenwerth-Nolan to postulate a specifically motor memory image that facilitated recall.

If the present hand-shape classes can evoke "motor images" that function as do spatial images (and in fact these may not be entirely separable), they too would be represented in some medium that allows manipulation and interrogation. Further, if judgments about manual interaction with objects make use of the same medium, those judgments could be facilitated by advance activation of relevant hand-shape prototypes. In a strong form, our hypothesis is that motoric interactions can be cognitively simulated, and that the results can be interrogated and evaluated. A priming effect would arise in the present task, then, because it would allow certain parameters of the simulation to be prepared in advance.

In the present studies, a training procedure was used to guide interpretation of the hand-shape cues used as primes, prior to the priming trials themselves. In the first four studies, this procedure was intended to associate each cue with an overt manual response. In the training task, subjects were presented with a cue and they were to make the actual hand shape; such training trials were repeated until asymptotic performance was reached. (In the priming trials themselves, no hand shape was formed, but rather, the prime was followed by the sensibility judgment.) In contrast, in Experiment 5, the training elicited a verbal response (e.g., "poke") to the prime cue, rather than an overt hand shape. If the priming effect is limited to the situation where the training elicited a manual response, and hence is eliminated with the vocal training, this would constitute evidence for a functional representation associated with the relevant motor system, as opposed to exclusively verbal/semantic priming.

Note that there are two binary features designating the hand shapes of interest here, and both bits of information are necessary to fully describe a shape. For example, in Experiments 1-3, the terms "touch" and "grasp" represented the prehensility (extension/flexion) dimension, whereas "hand" and "finger" represented the size dimension. This cueing paradigm also allows us to prime just a single feature, for example, flexion by the prime "grasp." Neural research suggests that the hand often functions in a synergistic pattern specified by specialized controllers (e.g., Gibson, Houk, & Kohlerman, 1985; Humphrey, 1986). If it were maintained in cognitive representations of the hand, this wholistic pattern of responding would necessitate specification of both dimensions of the hand configuration, in which case effects of partial primes would not occur.

However, there is a literature, albeit somewhat controversial, regarding effective single-dimension precueing of overt motor performance (e.g., Goodman & Kelso, 1980; Requin, Semjen, & Bonnet, 1984; Rosenbaum, 1980). Suppose, for example, that a subject makes a movement defined by the arm moved, the direction of movement, and the distance moved. Advance signaling of a single feature of this type has been found to facilitate the subsequent execution of the overt action (Rosenbaum, 1980). This research suggests that a partial prime might facilitate sensibility judgments about actions with objects.

It should be noted that our method relies heavily on an analysis of prime "benefit," about which critical issues have been raised (Jonides & Mack, 1984). Basically, these issues pertain to whether neutral (control) prime and informative prime conditions are adequately matched in all ways except for informativeness. In general, we have been attentive to this issue and have included several manipulations and measures designed to assess potential problems. We will allude to these as they arise and will evaluate the paradigm's adequacy in the final discussion.

Experiment 1

Experiment 1 was intended to determine whether priming effects could be elicited by hand-shape cues. Accordingly, we maximized the possibility for such effects, by instructing subjects to attend to the prime, by indicating its potential relevance to the sensibility judgment, and by using a substantial stimulus onset asynchrony (SOA -- 750 ms). The primes were brief verbal labels designating hand shapes or their component dimensions; the neutral prime ("blank") was also a short verbal label. Subjects were trained on the labels' meaning by a preliminary task, in which they were given a cue and asked to make the appropriate hand shape.

Method

Subjects. A total of sixteen undergraduate students in the introductory psychology course at the University of California, Santa Barbara participated in the experiment as a means of satisfying course requirements.

Stimuli. The stimuli included four verbal labels, which were to be used to designate particular hand shapes. Each label identified a value on one of the two hand-shape dimensions. The labels for the prehensility dimension were "touch" and "grasp," which correspond to nonprehensile and prehensile, respectively. The labels for the hand size dimension were "finger" (small size) or "hand" (large size). The size dimension was given first. Thus the poke shape was characterized by the combination "finger touch", pinch by "finger grasp", palm by "hand touch", and clench by "hand grasp." These four cues were used during the initial training session and again during the main experiment.

For use during the main experiment, 20 "sensible" and 10 "nonsensible" object-action target phrases were constructed for each of the four hand-shape classes (a total of 80 sensible and 40 nonsensible phrases). A sensible phrase described a reasonable action that could be performed with a certain object (e.g., "crumple a newspaper") whereas a nonsensible phrase described an action that was highly unlikely to be done with the object (e.g., "crumple a window"). A sensible phrase was paired with one of the four hand shapes, in that the given shape was likely to be used to effect the action. For example, "crumple a newspaper" would be paired with the clench shape.

The sensible phrases, and their pairing with particular hand shapes, were based primarily on data of Klatzky et al. (1987). They included object/action pairs that had been given a high rating in conjunction with the hand shape in the earlier study. The experimenters also generated several comparable object-action pairs in order to complete the stimulus set for each hand-shape class. Phrases were constructed so as to preclude a high degree of semantic association between the object name and the action (eliminating, e.g., wring a towel), as well as to minimize the amount of verb repetition across phrases.

The nonsensible phrases were constructed by re-pairing the actions and objects within a particular hand-shape class; thus each nonsensible phrase could be identified with a hand shape. The re-pairing was done under the constraint that a nonsensible combination result, as judged by the experimenters.

Procedure and Design. The study comprised a main experiment, preceded by training trials.

Main Experiment. The subject's task on any trial during the main experiment was to decide if a target phrase was sensible or not sensible. The target phrase was preceded by the brief presentation of a one- or two-word prime. Primes were designed to provide either no information about the hand shape used in the activity described by the target, information about one dimension of the hand shape, or information about both dimensions. Hence there were four different priming conditions: 1) neutral priming (i.e., the word "blank" served as prime); 2) priming of the prehensility dimension only (either "touch" or "grasp" served as prime); 3) priming of the hand size dimension only (either "finger" or "hand" served as prime); and 4) priming of both prehensility and hand size. There were no negative priming trials in the experiment. That is, no phrase from one hand-shape class was assigned a partial or full prime that signaled a different class.

The subject was instructed to pay attention to the prime because it could provide information about the way the hand might be shaped to perform the subsequently described activity. The instructions pointed out that the only case in which no hand-shape information was provided by the prime was when it was the word "blank." The subject was told to make a sensibility judgment for each phrase on the basis of whether or not the phrase described a reasonable action that could be performed with the object, and that the congruence of the prime should not enter into the judgment.

Four blocks of 120 phrases each were constructed for use in the main experiment. A block contained all 80 sensible and 40 nonsensible phrases, in random order. Within the block, each phrase was randomly assigned to one of the four priming conditions, under two constraints. First, over all blocks, every phrase appeared exactly once in each of the four priming conditions. Second, an equal number of sensible phrases, and an approximately equal number of nonsensible phrases, from the four hand-shape classes appeared in each of the priming conditions within a block. Presentation of the four blocks to subjects was arranged according to a Latin Square. An IBM PC-AT controlled display of stimuli and collection of subject responses and reaction times.

The design contained a total of 128 different conditions (4 priming conditions X 4 hand shape classes X 4 blocks of trials X 2 sensibility values, the latter in a 2:1 ratio) over 480 trials and was run completely within-subjects. The main experiment lasted approximately 1.5 hours and began after a brief rest period following completion of the training period.

During the main experiment, a trial followed the following time-course. First, a fixation point (*) appeared in the center of the monitor screen for 1000 ms. Next, a prime from one of the four possible priming classes (neutral, prehensility only, hand size only, full hand shape) was displayed in the center of the screen for 500 ms, with the size cue above the prehensility cue. The screen was then cleared for 250 ms before the target phrase was displayed in the center. Hence the SOA was 750 ms. The target phrase remained visible until the subject indicated a sensibility judgment. The subject pressed a "yes" key (in the P keyboard position) if the phrase was a reasonable description of an activity being performed with an object, or a "no" (Q) key for phrases judged to be unreasonable. No feedback was displayed. After the response, the screen cleared for 2000 ms. and the next trial then began. Sensibility judgments and RTs were written to a computer file for later analysis.

At the start of the main experiment were 10 practice trials involving all four priming conditions and phrases from all four hand-shape classes, both sensible and nonsensible. None of the practice phrases were used in the actual experiment. At this point, subjects were given feedback about their sensibility judgments for each practice phrase, in order to give them an idea about what types of phrases constituted sensible and nonsensible object-action descriptions.

Training Session. Before the main experiment, subjects were trained on the meaning of the primes. The experimenter mimed each hand shape while describing the prime's meaning. Subjects were informed about the meaning of each dimension separately, although they were trained only on the full primes.

The training task required the subject to respond to a two-word prime (identifying both dimensions of the hand shape) as quickly as possible, by actually forming the corresponding hand shape. The subject initiated each trial by pressing the space bar, in response to the appearance of a fixation point centered on the monitor screen. This started a timing routine and displayed a prime, which appeared in the center of the monitor screen (size above prehensility) and remained visible until the response. The subject was instructed to press the bar a second time as soon as he or she understood the hand-shape cue and then immediately to lift the right hand and produce the corresponding shape. The second bar-press stopped the clock and cleared the screen. The RT for each trial was displayed in the upper left-hand corner of the screen for 2 s so that the experimenter could monitor the subject's performance. The screen then cleared for 1 s before the next fixation point appeared, starting another trial. The experimenter made note of any hesitations or other errors in the subject's hand-shaping performance.

The training session included ten sequences of eight trials each, with an equal number of trials per hand-shape class in each block. Order of the trials within each sequence was randomized, as was the presentation order of the sequences to each subject. A criterion RT level of 750 ms was designated to be reached before the subject could begin the experiment proper, to ensure that subjects would be able to read primes presented during the main experiment. If any subject failed to reach this level of performance within at least 7 trials in the 10th sequence, he or she participated in additional trials until RT reached asymptote at or below 750 ms for a sequence of 7/8 trials. No subject in this or subsequent experiments failed to reach criterion by the end of the designated additional trials. The entire training session lasted approximately 15 minutes. Subjects' RTs were written to a computer file for later analysis, and errors were recorded manually by the experimenter.

Results

The training-session results will be described first, followed by the results of the main experiment.

Training Session. Fourteen of the sixteen subjects reached the criterion level of performance within the initial set of 80 trials. Mean RT is plotted over blocks of 16 trials for each hand-shape class in Figure 1. The figure excludes erroneous responses (hesitations or inappropriate shapes), which constituted approximately 8% of trials. Two subjects who failed to reach the RT criterion (at least 7 of the last 8 trials below 750 ms) during the first 80 trials were given 36 additional trials. Both subjects met the criterion during the extra training trials and continued to participate in the experiment. The figure separates these subjects from the remainder.

Insert Figure 1 about here

Figure 1 indicates that the average RT for each class was less than 750 ms after only 16 trials had been completed. In addition, all of the RT functions reached asymptote below the 500- ms level. This indicates that the 750-ms SOA was sufficient time to read primes presented during the main experiment.

Excluding the two late-criterion subjects, the mean RTs were examined in an analysis of variance (ANOVA) with two factors:

hand Shape class and Block of trials. There were main effects of Block, $F(4, 52) = 55.34$, $p < .0001$, and of Shape, $F(3, 39) = 2.97$, $p < .05$. "Poke" and "clench" responses were generally produced faster than "pinch" or "palm" responses. Although differences in mean RT among the hand shapes appeared to diminish over blocks, the interaction did not approach significance.

Main Experiment. As in the training task, the data are mean RTs for correct trials. Any trial in which RT exceeded a subject's overall mean RT by 3 sd or more was deleted from the data set. In addition, if a subject judged a sensible phrase as nonsensible or vice versa, the response was classified as incorrect and the trial was deleted. Target phrases that elicited consistently incorrect responses (i.e. on at least 3 of the 4 repetitions, from 25% or more of the subjects) were deleted from the analysis. One sensible and two nonsensible phrases were deleted on this basis. The mean error rate over subjects, including deleted stimuli, was approximately 5%. The analyses for sensible and nonsensible trials will be described separately.

In all experiments reported here, an initial ANOVA was performed on all of the principal factors, for the judgments of sensible stimuli. In none of these cases did Shape and Block interact. Therefore, we report ANOVAs conducted by pooling over one of these factors -- i.e., including Shape when pooling over Blocks, and Blocks when pooling over Shape. Pooling over Blocks also allows a separate analysis in which items are the unit of observation. An item analysis involving Block was not possible given the design. As the potential stimulus pool here is not indefinitely large, the F-2 statistic based on items is somewhat questionable. We will report it only when it is not significant and the F-1 based on subjects is significant, in which case item-specific effects are indicated.

Table 1 shows the means over subjects for the two factors, Prime and hand Shape. Figure 2 gives the differences between RTs with neutral primes and each of the three other types of primes. Similar data are shown for three subsequent experiments. The analyses indicated that the only reliable effect was that of Prime. The Subject ANOVA revealed a main effect of Prime, $F(3,45) = 3.07$, $p < .05$, and Shape, $F(3,45) = 7.04$, $p < .0001$. However, the effect of Shape was not significant when analyzed over items, $F(3,75) < 1$. Tests (one-tailed, over subjects) were conducted to determine whether the neutral-prime RT was greater than each of the prime conditions. The only significant comparison was between the neutral and full primes, $t(15) = 1.78$, $p < .05$.

Insert Table 1 and Figure 2 about here

The second ANOVA (over Subjects only) included the factors Block and Prime, pooling over hand-shape class. Figure 3 (left panel) displays the RT functions for the four priming conditions across blocks. There were effects of Block, $F(3,45) = 37.66$, $p <$

.0001, and Prime, $F(3,45) = 3.18$, $p < .05$. The interaction was of marginal significance, $F(9,135) = 1.68$, $.05 < p < .10$. This trend reflects the apparent emergence of a priming effect for the single-dimension cues, in later blocks, whereas the effect of the full prime is evident in all blocks. However, individual ANOVAs comparing each prime condition to the neutral condition over blocks revealed no significant Prime by Block interactions.

Insert Figure 3 about here

We turn next to the analyses of trials with nonsensible phrases. Figure 3 (right panel) displays the mean RT functions for each priming condition, over blocks. Generally, effects were minimal and will not be reported in detail. An analysis conducted by pooling over blocks revealed no effect was reliable over both subjects and items. An ANOVA on Block and Prime showed only a main effect of Block, $F(3,45) = 24.67$, $p < .0001$.

Discussion

The results of this experiment can be briefly summarized. The predicted effect of a hand-shape prime on judging the sensibility of a phrase was obtained. The effect did not significantly interact with hand shape nor with block of trials, being evidenced for all four shapes and all blocks. In contrast, priming with a partial hand-shape cue (size or prehensility) did not significantly facilitate responses relative to a neutral condition (although there was a trend toward a small effect in later blocks), and no priming effects effects emerged for nonsensible phrases. It is also noteworthy that subjects very quickly learned to make the appropriate hand shape in response to the verbal cue.

Experiment 2

One potential reason for the lack of partial priming effects (i.e., no facilitation due to cueing only the size of the hand shape or its prehensility) in Experiment 1 is that subjects were not explicitly trained on partial cues. Accordingly, Experiment 2 replicated the first study with such a manipulation, also adjusting the neutral prime to more closely resemble partial and whole prime conditions.

Method

The method was identical to Experiment 1 with the following changes. Thirteen subjects participated. The deleted items from Experiment 1 were replaced with new items, generated by changing an object (for the sensible item) and re-pairing actions and objects (nonsensible items).

The training session was modified to include training on partial primes, by including trials in which the two cues (for the prehensility dimension, grasp vs. contact; for the size dimension, finger vs. hand) were separated by 500 ms. The temporally separated cues simulated the partial priming condition in the main experiment (where just one label was presented) as closely as possible. However, it was necessary to include both cues during training, in order to elicit a hand shape. The subject was instructed to produce the appropriate shape as soon as possible after the second cue appeared. Eight sequences of twelve trials each were presented in the training phase. Trials were divided equally among the four hand-shape classes and three types of cue presentation: prehensility displayed first, hand-size dimension first, or both displayed simultaneously.

There were three types of neutral prime in the main experiment, so that the presentation varied in the same way as the meaningful primes. These were: "blank" appearing above the fixation point; "blank" appearing below the fixation point; and "blank" appearing in both locations. The three types were distributed as equally as possible within each block of 120 phrases and each hand-shape class.

The two dimensions of the hand shape were displayed with the size cue above the prehensility cue for half the subjects, and the reverse for the other half, during both phases of the study.

Results

Training Session. All thirteen subjects reached the criterion level of performance within the initial set of 96 trials. The mean RT for each hand-shape response was less than 750 ms after 24 trials had been completed. Moreover, all of the RT functions reached asymptote below the 600 ms level (cf. 500 ms in Experiment 1).

Due to sparse data, it was not possible to examine all factors in a single ANOVA. As an initial ANOVA revealed no Shape effect, mean RTs pooled over Shape were compared in an ANOVA with three factors: cue Presentation (i.e. temporally separated vs. simultaneous), Block, and Format (size cue above vs. below prehensility cue). There was a main effect of Presentation, $F(2,22) = 105.85$, $p < .0001$, reflecting faster responses when cues were temporally separated. This is not surprising, in that the RT period began with the second cue in this condition, so that it did not include processing time for the first. This does indicate, however, that some information could be extracted from the first cue before the second appeared. There was also a main effect of Block $F(3,33) = 21.57$, $p < .0001$. The Format effect did not approach significance, $F < 1$.

Main Experiment. Incorrect and anomalous responses constituted approximately 5% of all trials. Six nonsensible items were deleted (2 each from "palm", "pinch", and "clench") because of consensus that they were sensible (two of these were replacements generated after Experiment 1), but no positive items were deleted.

The analysis on the data pooled over Blocks examined the effects of Prime, Shape, and Format. The Subject ANOVA revealed main effects of Prime, $F(3,33) = 6.92$, $p < .001$, and Shape, $F(3,33) = 3.77$, $p < .05$. The effect of Format did not approach significance. However in the item analysis, the effect of Shape was only marginal, $F(3,76) = 2.18$, $p = .10$. Table 2 shows the mean RTs by Prime and Shape. Figure 2 gives the differences between RTs with neutral primes and each of the other three types of primes. Tests indicated that the neutral prime was significantly slower than the full prime, $t(12) = 3.72$, $p < .005$, and the size prime, $t(12) = 2.50$, $p < .05$.

Insert Table 2 about here

The second ANOVA was conducted over subjects only and examined the factors Block, Prime, and Format, pooling over Shape. There were significant main effects of Block, $F(3,33) = 61.70$, $p < .0001$, and Prime, $F(3,33) = 6.81$, $p < .001$. There was also a significant Block X Format interaction, $F(3,33) = 4.03$, $p < .05$. The prehensility-above cue led to faster responses than size-above, but this format effect diminished over blocks (171 ms in Block 1 to 68 ms in Block 4). As it is of little importance here, it will not be discussed. There were no other significant interactions, although again (as in Experiment 1), the Prime X Block interaction was marginal, $F(9,99) = 1.71$, $p = .10$. Figure 4 (left panel) shows the mean RT functions for the four priming conditions across blocks. As in the first experiment, the facilitory effect of full primes was apparent in the first block of trials and persisted, whereas partial priming effects were evidenced only later. ANOVAS comparing each priming condition to the neutral condition over blocks indicated a significant Prime X Block interaction only for the prehensility cue, $F(3,33) = 6.89$, $p < .05$. The neutral was actually faster than the prehensility condition in Blocks 1 and 2, but significantly slower in Blocks 3 and 4, $ts(12) = 1.85$ and 2.47, $ps < .05$.

Insert Figure 4 about here

Trials involving nonsensible phrases were examined next. In the analysis conducted by pooling over Blocks, no effects were reliable over both subjects and items. The subject ANOVA on Prime, Block, and Format showed main effects of Prime, $F(3,33) = 3.84$, $p < .05$, and Block, $F(3,33) = 49.14$, $p < .0001$. Although the interaction was not significant, the Prime effect clearly emerges in later blocks. There was a significant Block X Format interaction, $F(3,33) = 6.32$, $p < .005$, similar to that for the sensible items. Figure 4 (right panel) displays the mean RT functions for each priming condition across blocks.

Discussion

Experiment 2 essentially replicated the first in showing effects of hand-shape primes. The training on partial primes did produce more robust effects, particularly for the size dimension, but primes were effective primarily when they designated both component dimensions of the hand shape. This suggests that the failure of partial primes is not due to a lack of training, but rather reflects some insufficiency of information to speed the response. This study also replicated the first in the fast training of hand-shape responses to the cues, and the lack of reliable priming effects for nonsensible phrases.

Experiment 3

The first two studies motivated attention to and interpretation of the prime. Experiment 3 was intended to reduce the role of attentional processes, by giving weaker motivation for reading the prime and reducing its presentation time. Priming effects under such circumstances would not necessarily mean automatic facilitation (cf. Posner & Snyder, 1975) but the manipulation should certainly reduce the strategic component of this effect, as well as demand characteristics. It also allows us to consider potential differences in processing time for neutral and informative primes.

Method

The basic method from Experiment 1 was used, with several changes. There were 15 subjects. Deleted items were replaced as for Experiment 2.

Partial priming was eliminated from both phases, leaving only two priming conditions. Thus the training phase was just as in Experiment 1. In the main experiment, each target phrase was primed twice with neutral cues and twice with a full prime, which designated both the prehensility and hand-size values. The prehensility label was displayed above the hand-size label for all subjects in both training and the main experiment, as this had been the faster condition in Experiment 2.

Two SOAs (250 and 500 ms) were used in the main experiment. Each block of 120 phrases was divided into four sub-blocks. The SOA alternated values between sub-blocks, with half the subjects starting with a SOA of 250 ms and half with 500 ms. The prime was displayed for the entire interval. The trials presented at each SOA sampled equally from all hand-shape classes and priming conditions, and responses were in a 2:1 ratio. Overall, each target phrase appeared once in each of the four SOA x Prime conditions.

Instructions for the priming trials neither directed subjects to pay attention to the prime nor mentioned its relevance to the task. At the end of the experiment, subjects were asked if they had (a) read the prime; and (b) determined its relationship to the target phrase.

The training session consisted of 12 sequences of 8 trials each, with trials divided equally among hand-shape classes. In the first 48 trials, full hand-shape cues were displayed; these were not erased until the subject made the bar-press response. Cues in the last 48 trials, also full primes, were shown for 250 or 500 ms, with the display time alternating between 8-trial sequences. The display time for the first sequence was 250 ms for subjects who began with that SOA value in the main experiment, and 500 ms for the remainder.

Results

Training Session. The training session was divided into two parts for analysis : 1) the first 48 trials, in which cues were displayed until the subject responded, and 2) the last 48 trials, in which display time alternated between two brief durations. The mean RT for each hand shape was less than 750 ms after only 16 trials. In fact, on trials 32-48, all 15 subjects were able to produce hand-shape responses in less than 750 ms. There was no evident disruption in RT at the subsequent shift to shorter durations.

The mean RTs for the first part of training (Blocks 1-3) were examined in an ANOVA with two factors: Block of trials and hand Shape class. There were main effects of Block, $F(2,28) = 42.60$, $p < .0001$ and Shape, $F(3,42) = 9.25$, $p < 0001$. There was also a significant Block X Shape interaction, $F(6,84) = 3.92$, $p < .005$. "Pinch" responses were uniformly slower than the other three hand shapes, and "clench" responses were fastest, in general, but times converged over blocks.

Two analyses were conducted with mean RTs from the second part of training. First, an ANOVA examining Block and Time (either 250 or 500 ms) revealed only a significant effect of Block, $F(2,28) = 6.36$, $p < .005$. Neither the effect of Time nor the interaction approached significance (both Fs < 1). The second ANOVA examined Block and hand Shape class, pooling over Time. There was a main effect of Block, $F(2,28) = 6.89$, $p < .005$, and a marginal effect of Shape, $F(3,42) = 2.18$, $p = .10$. The interaction did not approach significance. In short, by this point in training, display time and response class had little or no effect.

Main Experiment. Incorrect and anomalous responses constituted approximately 6% of all trials. Four nonsensible items were deleted (one from "poke" and "clench" and two from "pinch") due to consensus in judging them sensible, but no positive items were deleted.

The first analysis examined three factors, Prime, Shape, and SOA . The Subject ANOVA revealed significant main effects of Prime, $F(1,14) = 11.81$, $p < .005$, and Shape, $F(3,42) = 8.72$, $p < .0001$. However, as in previous analysis, Shape effects were not significant over items. The effect of SOA was not significant, $F < 1$, and there were no significant interactions. Table 3 provides the mean RTs for the different Prime X Shape conditions, by SOA. Although there is apparently more variability than before, the priming effects are reasonably consistent, and there is certainly no indication of a reduction in priming at the shorter SOA. Figure 2 shows the mean differences between RTs with neutral primes and full primes, pooled over SOA.

Insert Table 3 about here

The second ANOVA was conducted over Subjects only, and included the factors Prime, Block, and SOA. There were effects of Prime, $F(1,14) = 6.66$, $p < .05$, and Block, $F(3,42) = 40.12$, $p < .0001$. The interaction did not approach significance, $F < 1$. Again, the facilitory effect of full primes is present throughout the entire experiment. Figure 5 (left panel) displays the RT functions for the two priming conditions across blocks.

Insert Figure 5 about here

We next considered the effects of whether subjects had been attending to and interpreting the prime. In response to the post-task questions, 9/15 subjects indicated that they had read the prime; six said they had not. Nine subjects (not necessarily the same as those who had read the prime) were able to articulate a reasonable approximation of the relationship between the prime and the subsequent phrase. The mean priming effect for subjects who indicated reading the prime was 27 ms; for those who indicated not reading, it was 28 ms.

There were minimal effects revealed in the analyses of nonsensible trials. An Anova on Prime, Shape, and SOA showed no effects that were reliable over both subjects and items. The ANOVA over Prime, SOA, and Block showed only a main effect of Block, $F(3,42) = 30.05$. Figure 5 (right panel) displays the mean RT functions for the two priming conditions across blocks.

Discussion

This study showed that hand-shape priming facilitated sensibility judgments even in the absence of explicit instructions to attend to the prime. The effect obtained under a short priming interval was as great as that under a longer one. However, the effects here were less on the average than those in the first two experiments, where attention to the prime was encouraged. This suggests that strategic effects were considerably reduced by the present manipulation.

Did subjects have time to strategically process the briefly presented prime? The training session provides an upper limit on the average time to process a 250-ms prime -- it is approximately 450 ms. This value also includes the time to make the bar-press response. In the main experiment, the SOA plus the response interval for the 250-ms condition was approximately 1350 ms. This value also includes the actual key-press time. Assuming the two responses take about the same amount of motor preparation and execution time, the prime information was available for about the last 900 ms of processing. Thus it is certainly possible for attentional, strategic effects to have occurred here. On the other hand, effects were found even in the absence of conscious reading of the prime.

Experiment 4

In the previous experiments, the primes were all verbal, raising the possibility that verbal/semantic mediation may underlie the observed priming effects. For example, the term "grasp" may be semantically associated with "squeeze," if not "tomato." We note, however, that the absence of priming effects for nonsensible judgments, which used the same nouns and verbs as the sensible ones, casts doubt on this interpretation. Experiment 4 was intended to directly address this issue. Here, the primes were "icon" symbols of the appropriate hand shapes. As in Experiment 3, the instructions did not strongly encourage strategic processing of the prime.

Method

The method was similar to Experiment 1 (including the 750-ms SOA), with the following changes. There were 11 subjects. The instructions were nondirective about attending to and interpreting the prime, although subjects were told to look at it.

Icons rather than verbal labels were used to cue the different hand shapes. These embodied the two dimensions by mapping prehensile and nonprehensile shapes into the > and | symbols (representing flexed and extended fingers), and mapping size into the number of repeated shapes (1 vs. 4). Thus the poke shape was represented by "|", the pinch by ">", the palm by "||||", and the clench by ">>>>". The neutral prime was *, and the fixation point was X.

The training session was modified slightly. In initially explaining the icons, each was printed on a 5 x 8 card, and the experimenter mimed the corresponding hand shape while showing the card to the subject. No mention was made of a verbal label for the primed shape. On each training trial, the subject produced a hand-shape after an icon cue had been presented. Cues were displayed until the subject responded. There were 10 sequences of 8 trials each, distributed equally among hand-shape classes.

The icons indicate values on both hand-shape dimensions. Thus the primes on the sensibility-judgment trials were all "full;" there were no partial-prime conditions.

Results

Training Session. All eleven subjects reached the criterion level of performance within the initial set of 80 trials. Figure 6 displays mean RT plotted over blocks of 16 trials, together with similar functions from a subsequent study. Erroneous responses, which constituted approximately 6% of the trials, were excluded. Mean RTs for each hand shape were less than 750 ms after the first 16 trials. In addition, all of the RT functions asymptoted below the 600 ms level.

Insert Figure 6 about here

An ANOVA conducted with two factors, hand Shape class and Block, showed main effects of Shape, $F(3,30) = 3.54$, $p < .05$, and Block, $F(4,40) = 30.22$, $p < .0001$. The interaction was also significant, $F(12, 120) = 2.59$, $p < .005$, as the differences among RTs for the four hand shapes diminished across blocks, much as in previous studies.

Main Experiment. Incorrect and anomalous responses constituted approximately 5% of all trials. Four nonsensible items (two "pinch", "clench", and one "poke") were deleted due to consensus in judging them sensible, but no positive items were deleted.

Table 4 provides the mean RTs for an ANOVA conducted on two factors, Prime and Shape. Figure 2 gives the mean differences between neutral primes and full primes across different hand shapes. The ANOVA revealed a main effect of Prime, $F(1,10) = 10.84$, $p < .01$.

Insert Table 4 about here

The second ANOVA (over Subjects only) assessed two factors, Prime and Block, pooled over Shape. Figure 7 (left panel) shows the mean RT functions for the two priming conditions across blocks. As in the previous experiments, the facilitory effect of full primes is present in the first block and is maintained throughout the experiment. The ANOVA revealed main effects of Prime, $F(1,10) = 11.81$, $p < .01$, and Block, $F(3,30) = 44.91$, $p < .0001$, but no significant interaction ($F < 1$).

Insert Figure 7 about here

In general, analyses of nonsensible trials revealed minimal effects. The first analysis, on Prime and Shape, showed no significant effects. The ANOVA examining Prime and Block showed only a main effect of Block, $F(3,30) = 25.74$, $p < .0001$. Figure 7 (right panel) shows mean RTs plotted for the two priming conditions, across blocks.

Discussion

The icon cues used here appear to be very effective. Training proceeded about as rapidly as with the verbal cues. Most importantly, priming effects were obtained, of essentially the same magnitude ~~as~~ with the verbal cues under similar instructions. This suggests that the priming effect is not entirely mediated by the verbal/semantic system. It is, however, still possible that subjects learned to mediate from the icon to a covert verbal response, which in turn produced the priming effect. For example, the shape > may have elicited "pinch." This possibility led to Experiment 5.

Experiment 5

A stronger test of the assumption that priming involves activation of the motor system, rather than being exclusively based on the verbal/semantic system, is to eliminate manual motor training and substitute explicit verbal mediation. Accordingly, in this study, subjects were trained on the icon stimuli used as primes in Experiment 4, but they were trained to give the verbal responses "clench," "poke," "palm," and "pinch," rather than overtly making the hand shape. If verbal mediation underlies priming, it should still be as strong as previously. However, reduction or elimination of the effect indicates the necessity for activation of a representation associated with motor responses of the hand.

Method

The method was identical to Experiment 4, with the following changes: There were 12 subjects, who took part in a training session in which the response to an icon was vocalization of the verbal equivalent: pinch, palm, poke, or clench. A voice-activated relay was used to determine response time.

Results

Training Session. All subjects reached the criterion within 80 trials. Figure 6 displays the mean RT over blocks, along with the equivalent RT for Experiment 4 training. It appears that the vocal training led to slower responses overall than the bar press, but the approach to asymptote is essentially equivalent, and the asymptotic value is still well below the SOA of 750 ms. An ANOVA on Shape and Block revealed effects of the latter only, $F(4,44) = 31.29$, $p < .001$.

Main Experiment Incorrect and anomolous responses constituted approximately 5% of trials. One nonsensible item was deleted. Table 5 provides the mean sensible-item RTs for an ANOVA conducted on the factors Prime and Shape. The Subject ANOVA revealed a main effect of Shape, $F(3,33) = 5.01$, $p < .01$, but this was not significant in an ANOVA over items. The effect of Prime did not approach significance, $F < 1$, as the mean priming effect was -6 ms.[1] Only one subject showed a mean effect greater than 15 ms (i.e., 32 ms), and 7 of the 12 showed negative effects, up to -62 ms.

Insert Table 5 about here

Means for the second ANOVA by Prime and Block, pooled over Shape, are shown in Figure 8, left panel. Unlike the previous experiments, no facilitory effect is present. The ANOVA revealed effects of Block only, $F(3,33) = 26.28$, $p < .001$. The Prime effect showed $F < 1$. (A t-test on Block 4 was also nonsignificant.)

Insert Figure 8 about here

The analyses of nonsensible trials on Prime and Shape revealed no effects, and that on Prime and Block showed only a Block effect, $F(3, 33) = 17.16$, $p < .001$. Figure 8, right panel, shows mean RTs over Blocks for the nonsensible items in the two priming conditions.

Discussion

The priming effect was entirely eliminated under verbal training. This indicates that the motor system plays an integral part in facilitating interpretation of phrases describing hand/object interactions. The potential alternative interpretation of Experiment 4, in terms of verbal/semantic mediation to the prime, is not supported.

General Discussion

The present experiments document a priming effect invoked by a cue to shaping of the hand, which facilitates judgments about the sensibility of action-object pairings. This effect occurs over a range of prime-to-stimulus intervals, and under instructions that do not encourage attention to the prime. It is also found for both verbal cues and visual "icons" that more directly simulate the shape of the hand. Finally, priming is eliminated when subjects are initially trained to vocally respond to the prime, rather than to make an overt manual response. Thus the effect should not be attributed to purely verbal/associative priming.

The hand-shape categories used as primes here represent a crossing of two dimensions: the size of the hand surface, and whether the operative fingers are flexed or extended. The four shapes resulting from crossing these dimensions (labeled as pinch, poke, palm, and clench) show priming effects that do not differ significantly (although trends were sometimes evident in the various experiments).

Cues that evoked the full hand shape were more effective than cues to each dimension separately, and the two partial priming effects generally did not sum to that of the full prime. Such differences between partial and full primes would be expected on the basis of cue informativeness. Given that four shapes are relevant to the sensibility judgment, a partial prime conveys 1 bit of information (since it reduces the potential set to the two shapes that share the primed dimensional value) and a full prime conveys 2 bits. However, the effects of partial primes seem somewhat weak, given their informativeness. The full prime was also effective even at the beginning of the task, whereas partial priming effects increased over time and may reflect within-experiment learning.

An important consideration raised above concerns the general strategy of comparing neutral and informative primes. Jonides and Mack (1984) have noted aspects in which the two types of primes might differ other than sheer informativeness, thus artifactually affecting RT. None of these seems critical in our case, however.

One potential problem is differential attention to neutral and informative primes, due to differences in form, presentation at different sessions or blocks, different repetition rates, or processing time. However, we have carefully matched the primes for form and randomly interspersed them. The possibility of repetition effects is rendered minimal given that the principal priming effect (of full primes) did not vary over blocks, as would be expected from an accrual of differential repetition effects. (This is despite the fact that there was no training on neutral primes, which should start the main trials with their having low frequency and end with their having high frequency.) Processing-time differences are apparently minimal, as the results of Experiment 3 indicate the priming effect did not change with SOA. (It might be argued that priming effects apparently were reduced in Experiment 3, when shorter SOAs were used, but a comparison of the first two studies to the fourth, all using the same SOA, makes it clear that instructions, rather than SOAs, are responsible for the reduction.)

Another potential problem raised by Jonides and Mack, namely, different processing demands of neutral and informative primes, is substantially invalidated by the icon manipulation of Experiments 4 and 5, where all primes were very similar in representational format. Finally, we note that the use of partial primes adds a further control for artifactual priming effects. The fact that these primes did not substantially or consistently differ from the neutral condition indicates that artifactual differences are not strong here.

Having countered artifactual explanations, we can turn to the question of the underlying mechanism for the present priming effects. To do so, we must consider how the sensibility judgment task is performed. One model for the task might assume that these judgments are made on the basis of a search within semantic memory, with positive responses resulting from an "intersection" between the action and the object in the target phrase. For example, a strong association between "eat" and "carrot" would elicit a positive response; lack of such an association between "eat" and "basketball" would elicit a negative.

A problem with this account is that it fails to include any basis for facilitation by a hand-shape prime. Hand shapes are associated with so many objects that any distributed-capacity semantic-priming mechanism (e.g., Anderson, 1983) would be fatally diluted. At best, priming effects would be expected to emerge only after repetition of items. And if hand-shape representations in semantic memory mediated the response, thus allowing for priming effects, it would then be impossible to make "nonsensible" decisions. That is because the actions and objects for nonsensible items were re-pairings of sensible items associated with the same shape and hence would themselves intersect. Finally, a compelling argument against an interpretation entirely in terms of semantic processing is provided by the differences between motor and verbal training on the interpretation of the prime symbol: Only training with overt manual responses subsequently produced priming effects.

Our proposed model for this task assumes that a representation is constructed to instantiate the target phrase. This representation provides a means of cognitively testing the action performed on the object. Successful performance leads to a positive sensibility judgment. (Given the nature of our items, which included some nonsensible pairings that were motorically possible but semantically implausible, a check against semantic as well as motoric constraints should be included.) Within this model, priming effects occur because activation of a hand shape facilitates constructing the representation and/or simulating the action/object pairing. This indicates that the operative representation includes some depiction of the hand, shaped so as to interact with the object.

It is not surprising to find no systematic priming effects on nonsensible items. Often, the primed shape was simply inappropriate in this case, being yoked to the action. For example, the verb "eat" may be associated with very different shapes when paired with "carrot" and "artichoke leaf." Also, if there were no compatibility between action and object, there would be no appropriate shape to prime. Finally, priming effects on negative items may be tenuous because the prime's association with the item is essentially positive, but the appropriate response is negative, resulting in a form of response conflict.

Our account of the present effects has a clear similarity to proposals regarding the role of visuospatial imagery. For example, Jolicoeur and Kosslyn (1985) suggested that construction and interrogation of an image is necessary to verify properties of objects that are not represented by a direct semantic proposition (e.g., that a turtle has a short tail). In common with the present model is the assumption that there exists a medium of representation that can be used to verify the desired information. The critical assumption in the present case is that what is constructed includes a representation of the hand, in a particular shape, interacting with the object. Further, we have provided evidence for a motoric (cf. semantic) component to this representation.

If the representation is a motoric one, a question arises as to why effects of partial primes, representing separate dimensions of the response, were so small. Precueing tasks in the motor domain, as described above, involve partial primes and have found relatively robust effects. It should be noted, however, that the precueing paradigm typically uses very distinct response systems that operate independently from one another. Each dimension typically specifies an isolated set of effectors; for example, which limb is used, whether the hand flexes or extends at the wrist, and whether the shoulder moves right or left. The hand is quite different, often functioning in a synergistic pattern. To further address this question, one would need studies of precueing hand shapes in an explicit motor-response paradigm.

The previously reviewed literature on motor imagery indicates some ambiguity in distinguishing motor and visuospatial imagery. Similar ambiguity exists in the current situation. A visual as well as motoric component is suggested by subjects' spontaneous reports of "seeing" their own hand reach out and interact with the object as they made their decision. Resolution of issues regarding the format and medium of the representation will depend on evidence such as selective reduction of the priming effect when a processing load is placed on either the motor or visuospatial system.

In summary, the present studies have further established the existence of mental representations of prototypical hand configurations, by illustrating their utility in a "knowledge based" judgment task. The data from this task also suggest the possibility that answers are computed from information that is not readily represented in a verbal/semantic medium.

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TABLE 1 Mean RT (ms) in Sensible Trials of Experiment 1, by Prime and Shape, Pooled Over Block.

	----------HAND SHAPE----------				
PRIME CONDITION	POKE	PINCH	CLENCH	PALM	MEAN
SIZE ONLY	1031	1047	1011	1068	1039
PREHENSILITY ONLY	1071	1076	1041	1048	1059
BOTH DIMENSIONS	1020	1002	967	1000	0997
NEUTRAL	1096	1047	1051	1077	1068
MEAN	1055	1043	1018	1048	

TABLE 2 Mean RT (ms) in Sensible Trials of Experiment 2, by Prime and Shape, Pooled Over Block and Format.

	----------HAND SHAPE----------				
PRIME CONDITION	POKE	PINCH	CLENCH	PALM	MEAN
SIZE ONLY	974	1019	936	968	974
PREHENSILITY ONLY	1006	1042	948	1017	1003
BOTH DIMENSIONS	956	928	889	945	930
NEUTRAL	1022	1010	959	1013	1001
MEAN	990	1000	933	986	

TABLE 3 Mean RT (ms) in Sensible Trials of Experiment 3, by Prime, Shape, and SOA, Pooled Over Block.

		----------HAND SHAPE----------				
SOA	PRIME CONDITION	POKE	PINCH	CLENCH	PALM	MEAN
500	FULL	1117	1109	1065	1106	1099
	NEUTRAL	1149	1105	1103	1148	1126
250	FULL	1110	1075	1047	1126	1090
	NEUTRAL	1162	1116	1071	1124	1118

TABLE 4 Mean RT (ms) in Sensible Trials of Experiment 4, by Prime and Shape, Pooled Over Block.

	-----------HAND	SHAPE----------			
PRIME CONDITION	POKE	PINCH	CLENCH	PALM	MEAN
BOTH DIMENSIONS	1180	1179	1144	1172	1169
NEUTRAL	1237	1202	1199	1214	1213
MEAN	1209	1191	1172	1193	

TABLE 5 Mean RT (ms) in Sensible Trials of Experiment 5, by Prime and Shape, Pooled Over Block.

	-----------HAND	SHAPE----------			
PRIME CONDITION	POKE	PINCH	CLENCH	PALM	MEAN
BOTH DIMENSIONS	1055	1027	1016	1020	1029
NEUTRAL	1057	1030	987	1021	1024
MEAN	1056	1028	1001	1020	

Figure Captions

Figure 1. Mean RT in Experiment 1 training, over 16-trial blocks, by hand shape. Data are shown separately for subjects who did and did not reach criterion within 5 blocks.

Figure 2. Difference between positive-response RT for neutral and prime conditions, by primed hand shape, for all 4 experiments.

Figure 3. Mean RT in Experiment 1 for sensible (left panel) and nonsensible (right panel) judgments, by block of trials and prime condition.

Figure 4. Mean RT in Experiment 2 for sensible (left panel) and nonsensible (right panel) judgments, by block of trials and prime condition.

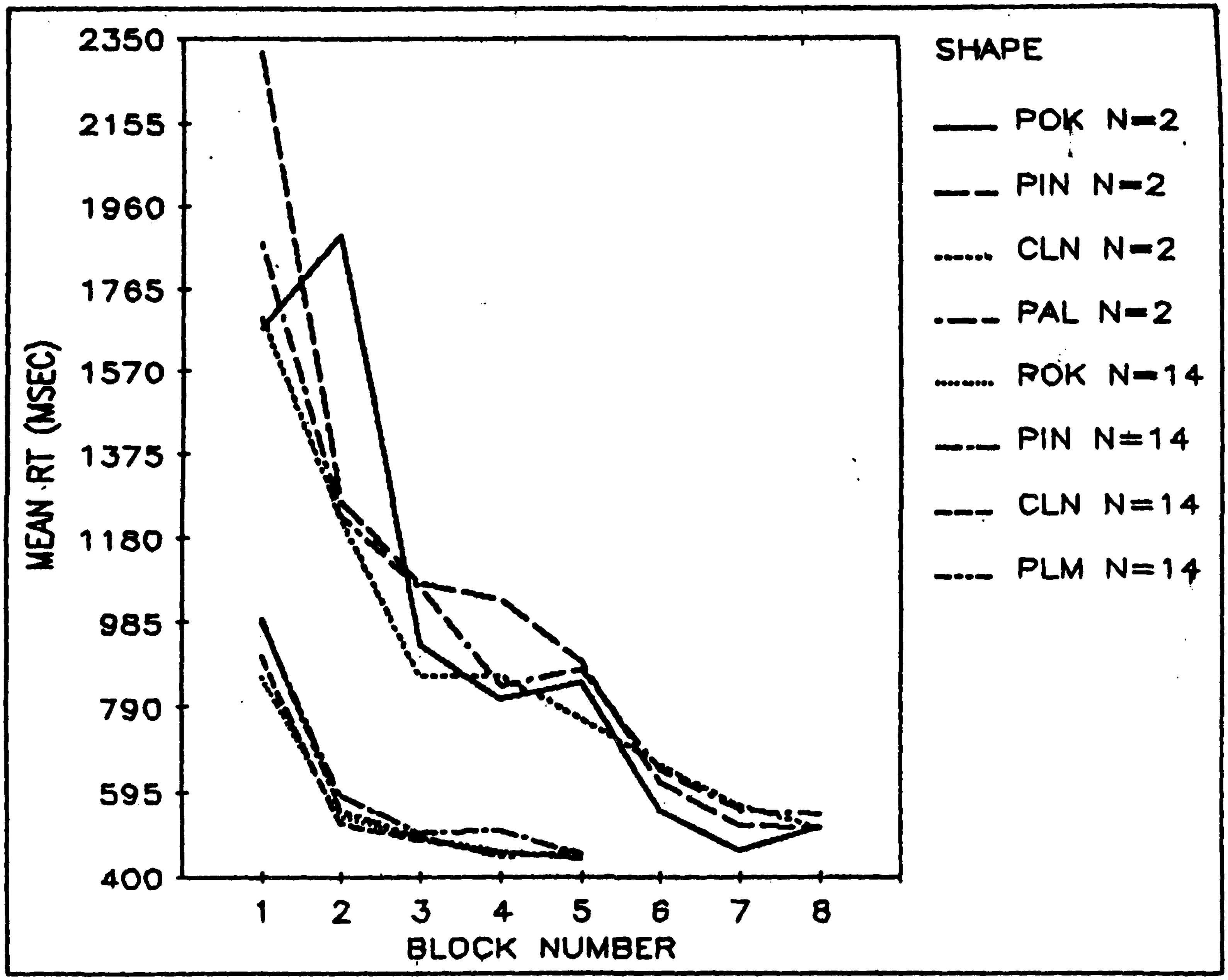
Figure 5. Mean RT in Experiment 3 for sensible (left panel) and nonsensible (right panel) judgments, by block of trials and prime condition.

Figure 6. Mean RT in training for Experiment 4 (motor) and Experiment 5 (vocal), over 16-trial blocks, averaged over hand shape.

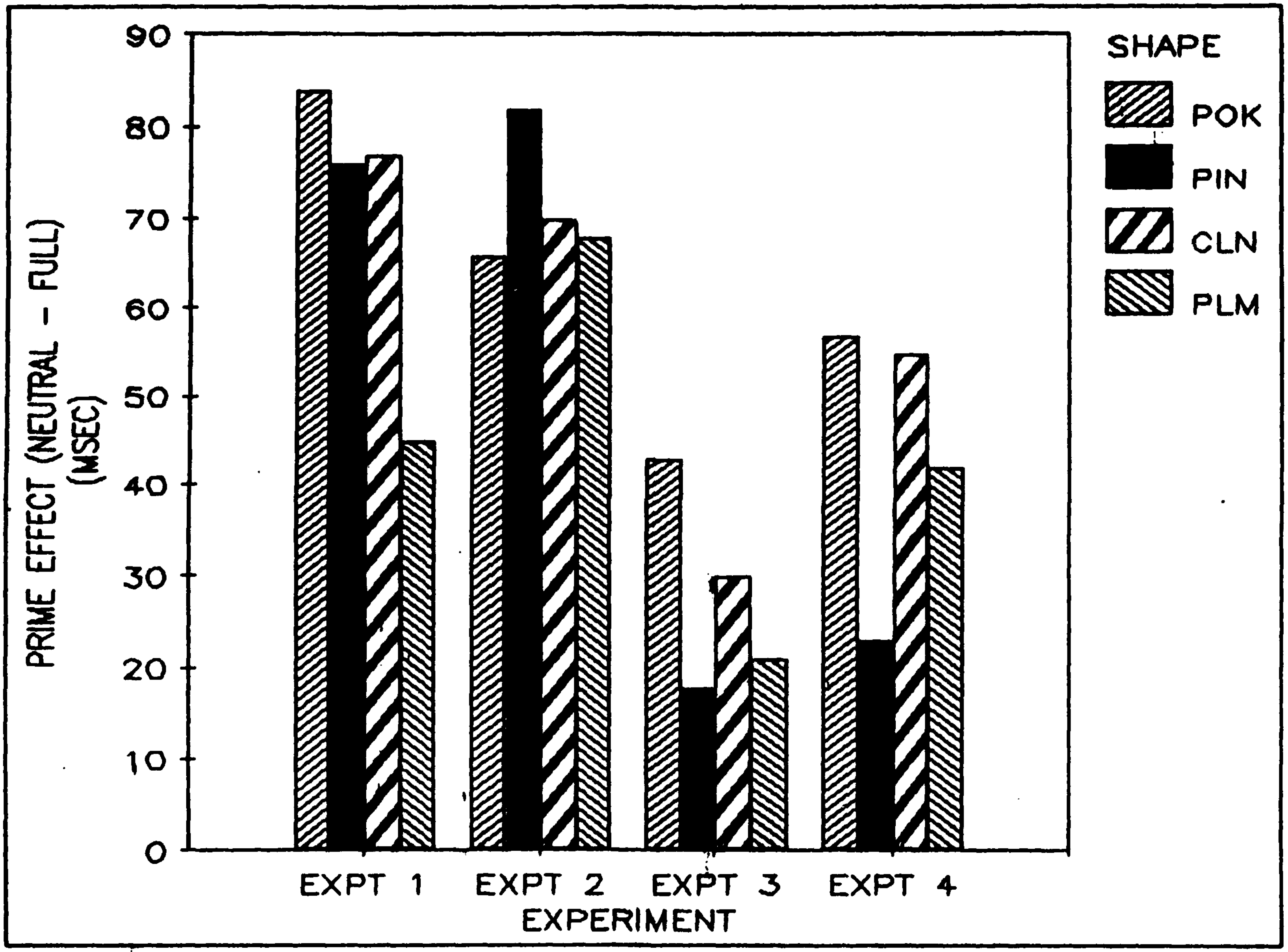
Figure 7. Mean RT in Experiment 4 for sensible (left panel) and nonsensible (right panel) judgments, by block of trials and prime condition.

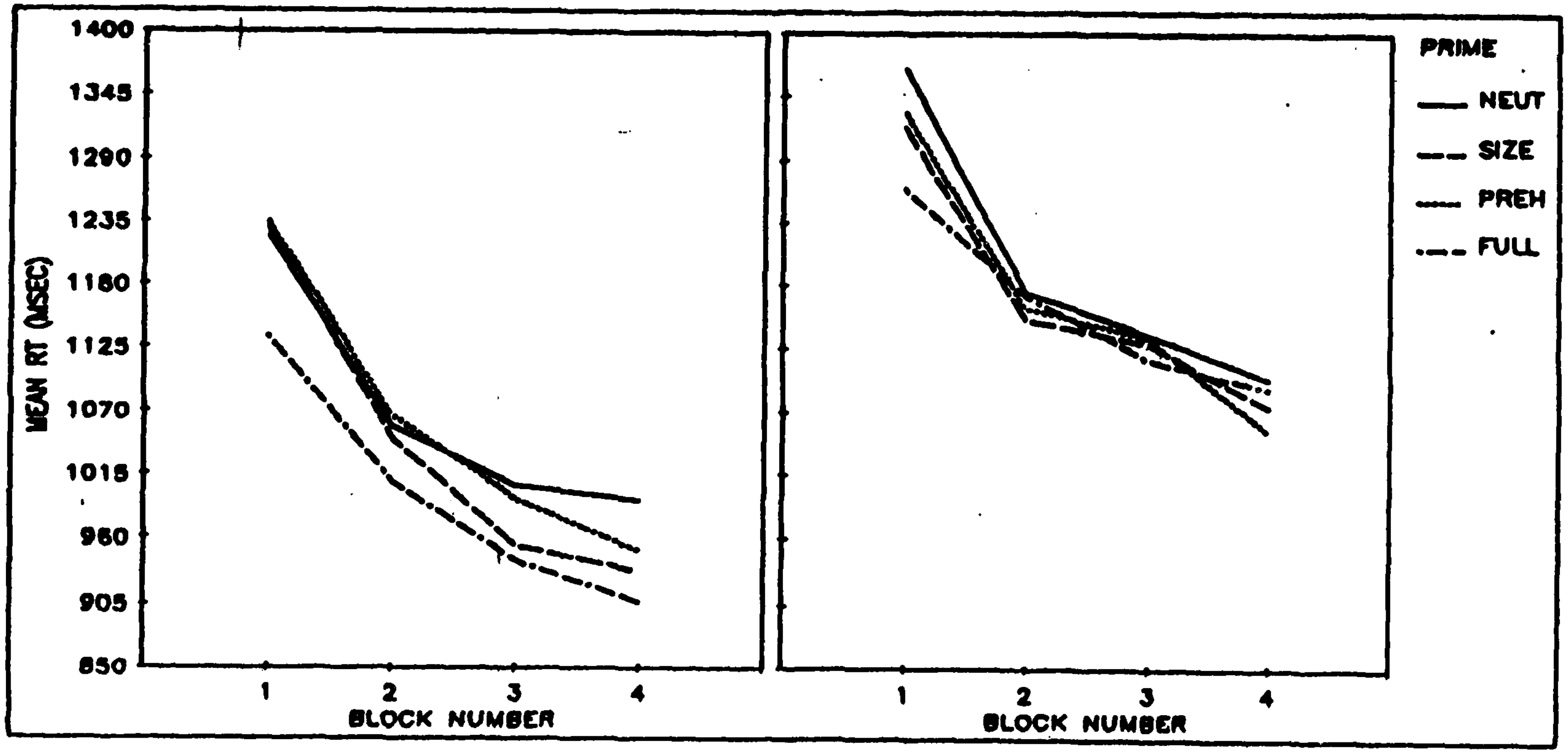
Figure 8. Mean RT in Experiment 5 for sensible (left panel) and nonsensible (right panel) judgments, by block of trials and prime condition.

1



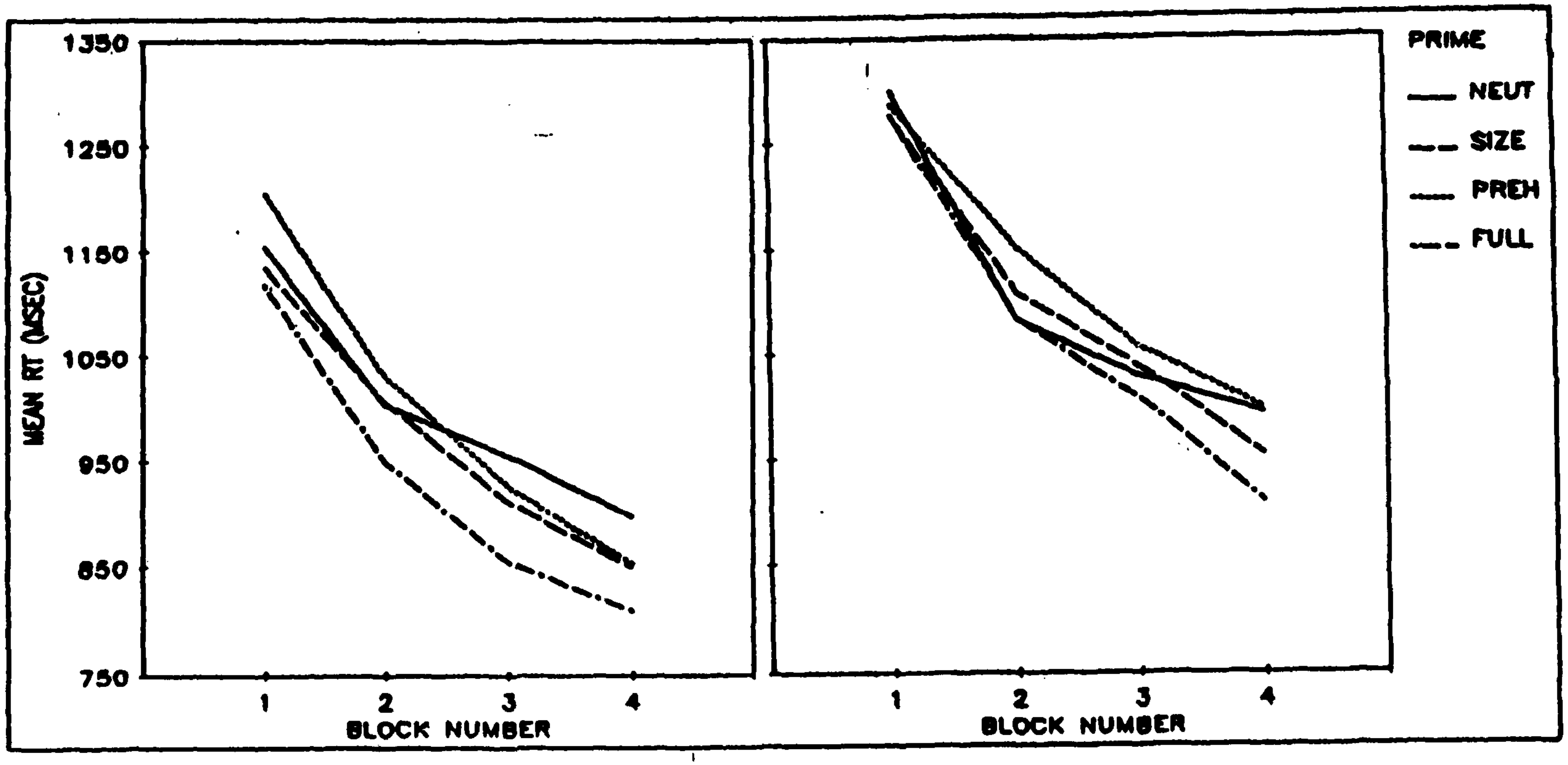
MEAN RT (MSEC)
2350
2155
1960
1765
1570
1375
1180
985
790
595
400
1 2 3 4 5 6 7 8
BLOCK NUMBER
SHAPE
POK N=2
PIN N=2
CLN N=2
PAL N=2
ROK N=14
PIN N=14
CLN N=14
PLM N=14


PRIME EFFECT (NEUTRAL - FULL)
(MSEC)
90
80
70
60
50
40
30
20
10
0
EXPT 1
EXPT 2
EXPT 3
EXPT 4
EXPERIMENT
SHAPE
POK
PIN
CLN
PLM



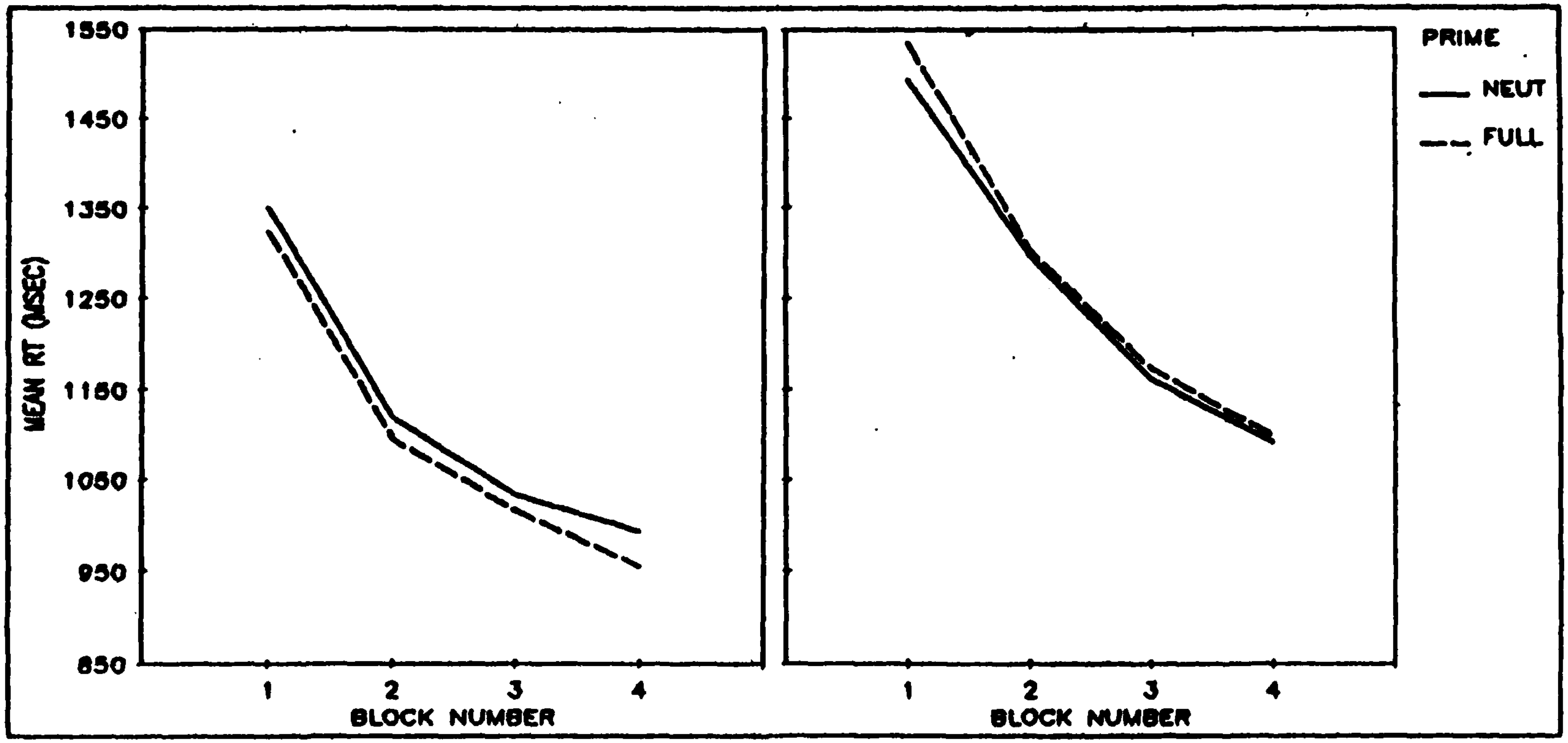
MEAN RT (MSEC)
1400
1345
1290
1235
1180
1125
1070
1015
960
905
850
1
2
3
4
BLOCK NUMBER
PRIME
NEUT
SIZE
PREH
FULL

(4)



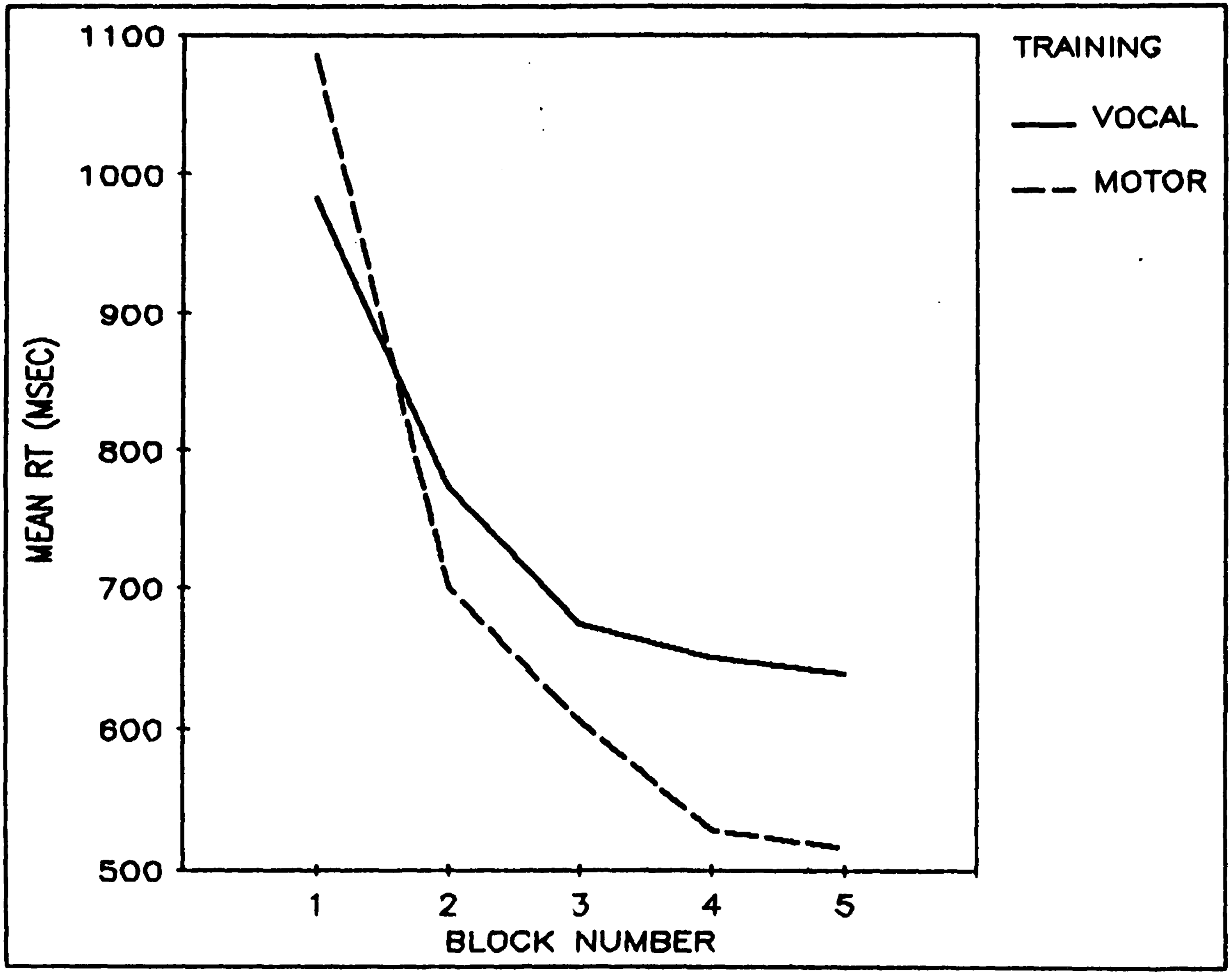
MEAN RT (MSEC)
1350
1250
1150
1050
950
850
750
1
2
3
4
BLOCK NUMBER
PRIME
NEUT
SIZE
PREH
FULL

5



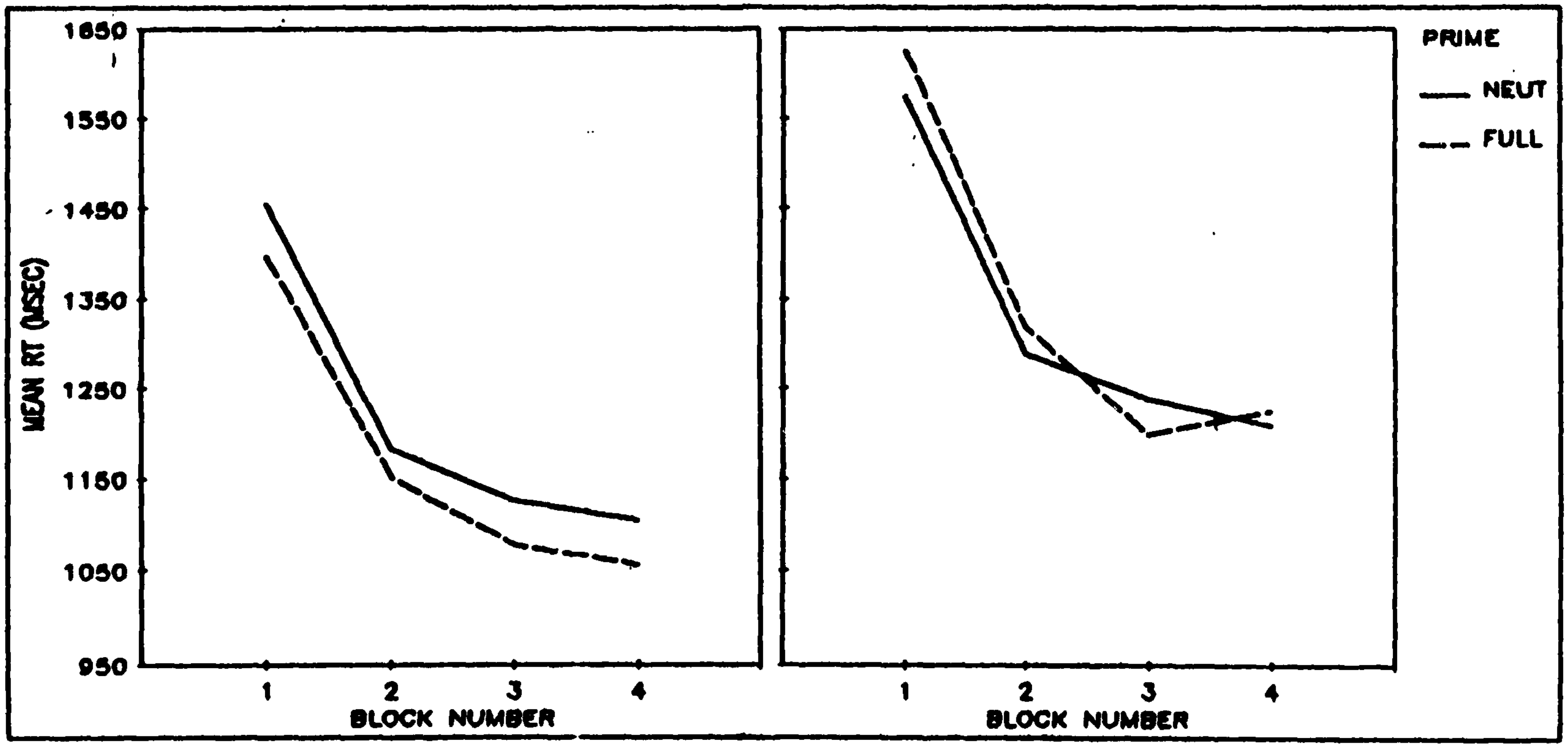
MEAN RT (MSEC)
1550
1450
1350
1250
1150
1050
950
850
1
2
3
4
BLOCK NUMBER
PRIME
NEUT
FULL

6

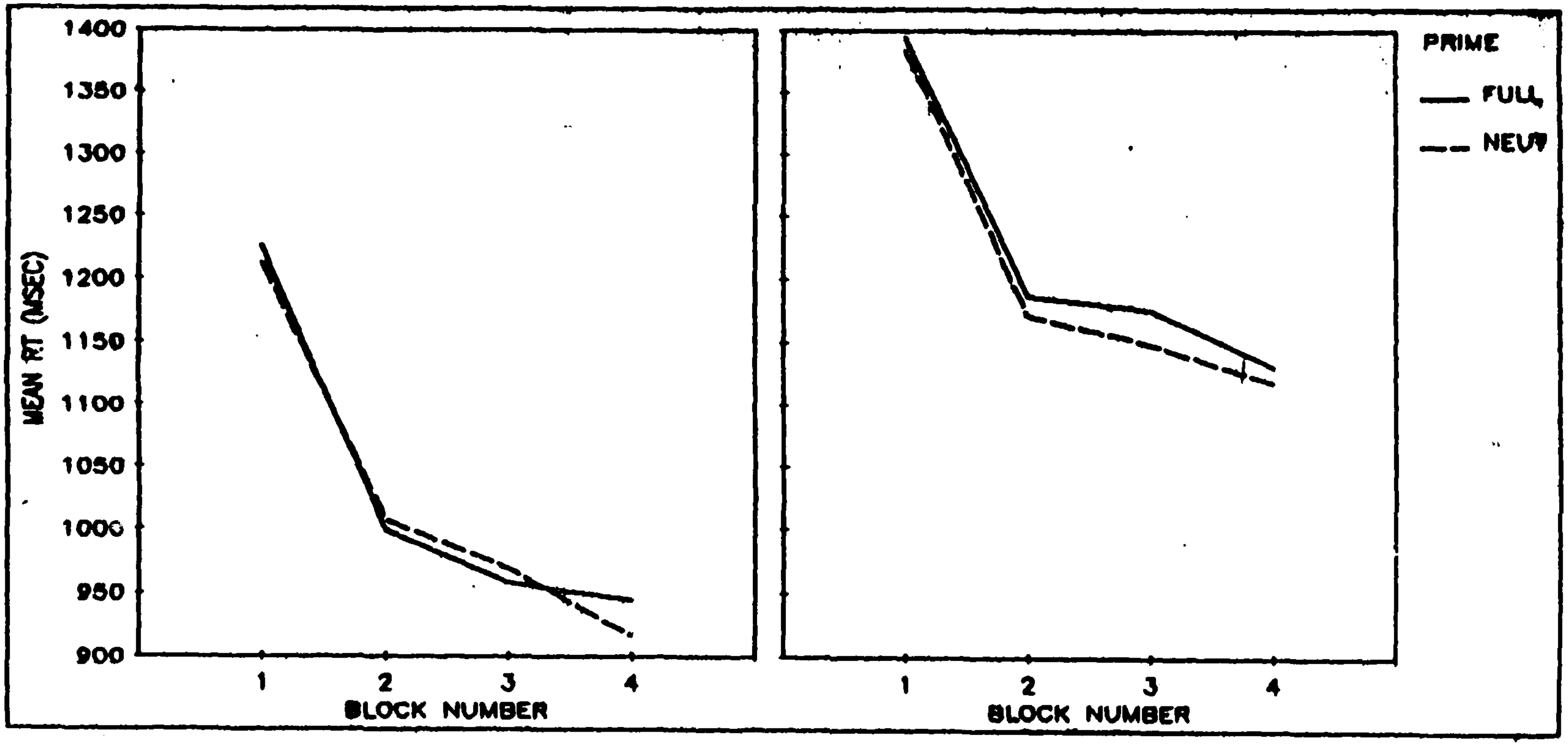


1100
1000
900
800
700
600
500
MEAN RT (MSEC)
1
2
3
4
5
BLOCK NUMBER
TRAINING
VOCAL
MOTOR

7



MEAN RT (MSEC)
1650
1550
1450
1350
1250
1150
1050
950
1
2
3
4
BLOCK NUMBER
PRIME
NEUT
FULL



MEAN RT (MSEC)
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
1
2
3
4
BLOCK NUMBER
1
2
3
4
BLOCK NUMBER
PRIME
FULL
NEU